

ADA 023959

EXXON RESEARCH AND ENGINEERING COMPANY

(D) FL

PHOTODISSOCIATION DYE LASER

Semiannual Technical Report

April 1976

Contract Period Covered: October 1, 1975 - March 31, 1976

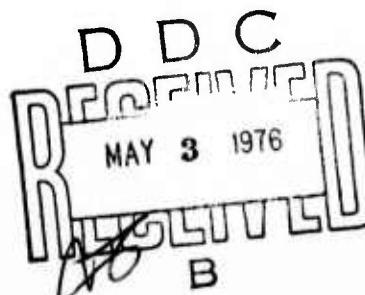
ARPA Order Number	1806, Amendment 16
Program Code	6E 20
Contractor	Exxon Research & Engineering Company
Effective Date of Contract	October 1, 1974
Contract Expiration Date	August 15, 1976
Amount of Contract	\$199,997
Contract Number	N00014-73-C-0048
Principle Investigator	Abraham Kasdan (201-474-3947)
Scientific Officer	Director, Physics Program ONR
Short Title of Work	Photodissociation Dye Laser

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U.S. Government

Sponsored By:

Advanced Research Projects Agency
ARPA Order No. 1806

EXXON/GRUS.3BEOB.76



ACCESSION NO.

NTIS	REF ID: A	<input checked="" type="checkbox"/>
P-2	10-16-68	<input type="checkbox"/>
DATA FILE		<input type="checkbox"/>
JUL 19 1968		
BY DISCRETE MEASURABILITY CORES		
FBI - WASH. D. C. - 20535		

[Handwritten signature over the stamp]

UNCLASSIFIED

EXON

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER <i>(Title and Summary)</i>	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
<i>6</i> Photodissociation Dye Laser.		4. TYPE OF REPORT & PERIOD COVERED Oct. 1, 1975-March 31, 1976
5. AUTHOR/AE Abraham Kasdan	6. PERFORMING ORGANIZATION NAME AND ADDRESS Exxon Research and Engineering Company Government Research Laboratories--P.O. Box 8 Linden, New Jersey 07036	7. PERFORMING ORGANIZATION NUMBER EXXON/GRUS.3BEOB.76
8. CONTROLLING OFFICE NAME AND ADDRESS Physical Sciences Division Office of Naval Research--Dept. of the Navy 800 N. Quincy St., Arlington, Virginia 22217	9. CONTRACT OR GRANT NUMBER(s) N00014-73-C-0048 ARPA Order-1806	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order No. 1806, Amend. 16--Program Code No. 6E 20
11. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Physical Sciences Division Office of Naval Research--Dept. of the Navy 800 N. Quincy St., Arlington, Virginia 22217	12. REPORT DATE April, 1976	13. NUMBER OF PAGES 44
14. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.	15. SECURITY CLASS. (of this report) UNCLASSIFIED	16. DECLASSIFICATION/DOWNGRADING SCHEDULE None
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Approved for public release; distribution unlimited.	18. KEY WORDS (Continue on reverse side if necessary and identify by block number) Photodissociation Tunable Liquid Lasers	
19. ABSTRACT (Continue on reverse side if necessary and identify by block number) The photodissociation dye laser (PDL) program is an effort to develop a new class of tunable liquid lasers operating in the visible region of the spectrum. In the PDL scheme, laser action is expected to occur between an excited electronic state and the ground electronic state of radicals produced by the photodissociation of specific classes of molecules in solution. This scheme is expected to result in several significant advantages over conventional dye lasers.	20. SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) UNCLASSIFIED 391338 ✓	

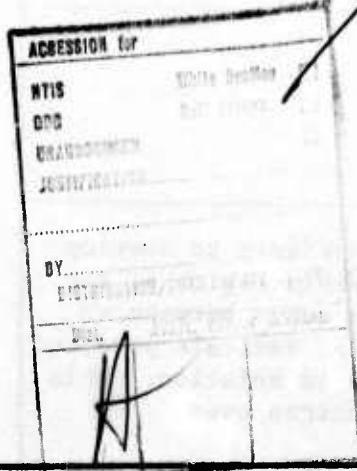
UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

During this reporting period we have completed our measurements on the potential PDL molecules that were selected from the hexaarylethane group, and have evaluated their use as active media for the PDL scheme.

Fluorescence intensity measurements as a function of excitation wavelength have been made on the hexaphenylethane-triphenylmethyl radical system. The measurements indicate that the optimum excitation source for the system is the N₂ laser. However, because the maximum gain is low (~.02 cm⁻¹), the length of active media the N₂ laser is capable of exciting is too short to overcome the single pass cavity losses. Xenon flashlamp pumping of this system has been considered, but the high intensities need (> 10 MW in the UV) makes such a pumping scheme unattractive.

In addition to hexaphenylethane, the other molecules that were synthesized in the early part of the program have been investigated. In particular, fluorescence spectra and lifetimes of pentaphenylethane, 1-p-biphenyl-1,1,2,2-tetraphenylethane, and 12-12' bifluoradenyl have been measured. These molecules have fluorescence lifetimes of ~10 ns. However, they exhibit no significant photodissociation into excited state radicals when excited in the UV (2600 Å).



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION.....	1
II. THE PHOTODISSOCIATION DYE LASER CONCEPT.....	4
III. PROPERTIES OF THE SELECTED PDL MOLECULES.....	8
A. Hexaphenylethane.....	8
B. Other Hexaarylethane Derivatives.....	12
IV. EXPERIMENTAL EFFORT AND RESULTS.....	17
A. Hexaphenylethane.....	17
B. Other PDL Molecules.....	22
(a) Pentaphenylethane.....	22
(b) 1-p-biphenyl-1,1,2,2-tetraphenylethane.....	22
(c) 12-12' bifluoroadenyl.....	25
(d) Triphenylmethyl chloride.....	25
V. CONCLUSIONS.....	27
VI. REFERENCES.....	28

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Photodissociation Dye Laser Molecule-- Structure and Kinetics.....	6
2	Energy Level Structure of the Hexaphenylethane-- Triphenylmethyl System.....	13
3	Mirror Image Symmetry of the Absorption and Fluorescence Spectra of the Triphenylmethyl Radical (Low Temperature Data).....	14
4	Hexaphenylethane Fluorescence Intensity as a Function of Excitation Wavelength.....	19
5	UV Absorption Spectrum of Hexaphenylethane.....	20
6	Fluorescence Spectrum of Pentaphenylethane.....	23
	Fluorescence Spectrum of 1-p-1,1,2,2 Tetraphenyl- ethane.....	24
8	Fluorescence Spectrum of 12-12' Bifluoradenyl.....	26

ABSTRACT

The photodissociation dye laser (PDL) program is an effort to develop a new class of tunable liquid lasers operating in the visible region of the spectrum. In the PDL scheme, laser action is expected to occur between an excited electronic state and the ground electronic state of radicals produced by the photodissociation of specific classes of molecules in solution. This scheme is expected to result in several significant advantages over conventional dye lasers.

During this reporting period we have completed our measurements on the potential PDL molecules that were selected from the hexaarylethane group, and have evaluated their use as active media for the PDL scheme.

Fluorescence intensity measurements as a function of excitation wavelength have been made on the hexaphenylethane-triphenylmethyl radical system. The measurements indicate that the optimum excitation source for the system is the N₂ laser. However, because the maximum gain is low ($\sim .02 \text{ cm}^{-1}$), the length of active media the N₂ laser is capable of exciting is too short to overcome the single pass cavity losses. Xenon flashlamp pumping of this system has been considered, but the high intensities need (> 10 MW in the UV) makes such a pumping scheme unattractive.

In addition to hexaphenylethane, the other molecules that were synthesized in the early part of the program have been investigated. In particular, fluorescence spectra and lifetimes of pentaphenylethane, 1-p-biphenyl-1,1,2,2-tetraphenylethane, and 12-12" bifluoradenyl have been measured. These molecules have fluorescence lifetimes of $\sim 10 \text{ ns}$. However, they exhibit no significant photodissociation into excited state radicals when excited in the UV (2600 Å).

I. INTRODUCTION

The photodissociation dye laser (PDL) program is an effort to develop a new class of tunable liquid lasers operating in the visible region of the spectrum. In the PDL scheme, laser action occurs between an excited electronic state and the ground electronic state of radicals produced by the photodissociation of specific classes of molecules in solution. In this study, a class of highly strained ethanes, the hexaarylethanes, is being investigated as potential laser media. Continuous wave operation of such lasers is expected based on the rapid relaxation of the terminal vibronic levels and the subsequent depletion of the electronic ground state by recombination to the original parent ethane structure. As in conventional dye laser systems, wavelength tunability is assured because the numerous vibrational and rotational modes of the complex molecule result in a manifold of quasi-continuous vibronic energy levels associated with each electronic level.

The photodissociation dye laser is expected to exhibit several significant advantages over conventional dye lasers. The radical can be thought of, to a first approximation, as a one-electron system. As a result, the electronic structure of the radical consists of doublet levels rather than the singlet and triplet level structure characteristic of the paired electrons of conventional dye molecules. Consequently, problems associated with non-radiative intersystem-crossing transitions which result in deleterious absorption by the lowest triplet level at the laser wavelength in conventional dye molecules are eliminated.

The second advantage of the PDL scheme is related to the upper laser level lifetime. In conventional laser dyes, the spontaneous radiative lifetime of the first excited singlet level is typically on the order of a

few nanoseconds. In radical systems, however, there is evidence, both theoretical and experimental, that the first doublet-doublet electronic transitions are in some cases, partially forbidden. From the point of view of the PDL scheme, this means that the radiative lifetime of the upper laser level can be one to two orders of magnitude longer than that exhibited by the upper laser levels of conventional organic dyes. Consequently, a larger population density in the upper level may be obtained, thereby allowing the possibility of generating higher laser output energy than can be presently attained with conventional dyes. This assumes that strong absorption from the upper level at the laser wavelength does not occur. In addition, the longer radiative lifetime favors the recombination of the radical ground state to the parent dimer at a sufficiently fast rate to permit a continuous population inversion and hence, cw laser action.

The aim of the current program is to demonstrate proof of principle of the PDL scheme. Towards that end, a number of promising chemical candidates from the hexaarylethane group of organic molecules have been synthesized and data has been obtained on those processes that are relevant to assessing their usefulness as PDL laser media.

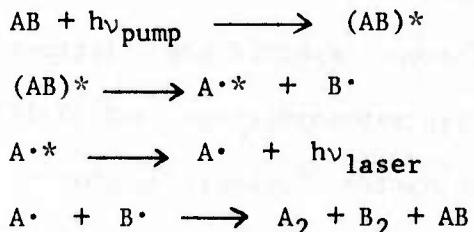
During the present reporting period we have completed our study of the hexaphenylethane-triphenylmethyl radical system. Fluorescence intensities as a function of excitation wavelength have been measured. Results of these measurements indicate that the optimum excitation wavelength for the hexaphenylethane system is at $\sim 3300 \text{ \AA}$. Consequently, the N_2 laser, with output at 3371 \AA is expected to be the best optical

pump. However, the low value of the maximum gain of $\sim .02 \text{ cm}^{-1}$ requires a longer excitation length, at fixed energy density, than realizable with an N_2 laser in order to overcome cavity losses and reach threshold. Since the hexaphenylethane fluorescence efficiency decreases as the excitation wavelength moves further towards the UV from $\sim 3300 \text{ \AA}$, the output of conventional flashlamp systems is poorly coupled to the excitation requirements of the hexaphenylethane molecule. Estimates show that a flashlamp system with output power in excess of 10 MW in the UV would be required to achieve $.02 \text{ cm}^{-1}$ gain over a 15 cm length, making such a pumping scheme highly unattractive.

In addition to hexaphenylethane, the other molecules that were synthesized in the early part of the program have been investigated. In particular, fluorescence spectra and lifetimes of pentaphenylethane, 1-p-biphenyl-1,1,2,2-tetraphenylethane, and 12-12' bifluoradenyl have been obtained. These systems however, exhibit no significant photo-dissociation into excited state radicals, and therefore will not fulfill the requirements of a PDL active media.

II. THE PHOTODISSOCIATION DYE LASER CONCEPT

In its most general form, the photodissociation dye laser may be understood as follows: A stable molecule, AB, in solution is optically pumped to its first excited singlet state. The absorbed pump energy exceeds the molecule's dissociation energy and two radicals are formed upon dissociation. The excess energy is partitioned as electronic and vibrational excitation in one or both of the radicals A[•] and B[•]. In particular, we consider radical A[•] to be electronically excited. A partial population inversion is produced between the first excited and the ground state of the radical. Laser action occurs in A[•] and the resulting A[•] and B[•] ground state molecules are unstable against recombination. The processes may be written as:



In the final recombination step, not all of the radicals form the original molecule AB, but the dimeric forms A₂ and B₂ are also produced. Continuous laser action would require replenishment of the starting material, AB. Let us consider in more detail the special case where B ≡ A so that the starting molecule is a symmetrical dimer.

The general energy level scheme for such a photodissociation dye laser molecule is shown schematically in Figure 1. The stable parent dimer, having no unpaired electrons, exhibits the usual singlet and triplet level structure. The ground and excited electronic singlet levels are denoted by D_{S₀}, D_{S₁}, . . . and the triplet levels are denoted by D_{T₀}, D_{T₁}, . . .

The lowest electronic levels of the radicals, obtained from the symmetric photodissociation of the dimer, are shown adjacent to the dimer structure. The radical, having a single unpaired electron, exhibits a doublet structure. In the figure the radical ground state is shown displaced upward in energy from the dimer ground state by an amount equal to the dimer dissociation energy.

The vibrational level spacing in both the dimer and radical ranges between 150-1500 cm^{-1} while the rotational spacing ranges between 15-150 cm^{-1} . Therefore, as in conventional dye lasers, a quasicontinuum exists for each electronic level comprised of the thermally broadened rotational and vibrational levels.

A characteristic of the photodissociation dye laser molecule is that the D_{S_1} and D_{T_0} levels in the dimer lie above the dimer dissociation energy. Consequently, upon optically pumping the dimer to D_{S_1} the molecule will undergo dissociation into two radicals. Dissociation may occur via two possible paths. The first is directly from the optically pumped D_{S_1} level. However, the D_{S_1} level may, in principle, undergo a rapid intersystem crossing to the D_{T_0} level. Dissociation of the dimer may occur from this level.

Upon dissociation, the excitation energy is partitioned between a manifold of levels in the quasi-continuum of both the excited and ground state of the radical. The radical ground state initially has a negligible population; consequently, a partial inversion in the radical can be produced. The stimulated emission is tunable as in conventional dye lasers because of the quasi-continuous distribution of the upper and ground levels. An interesting point is that for radicals considered suitable for the photodissociation dye

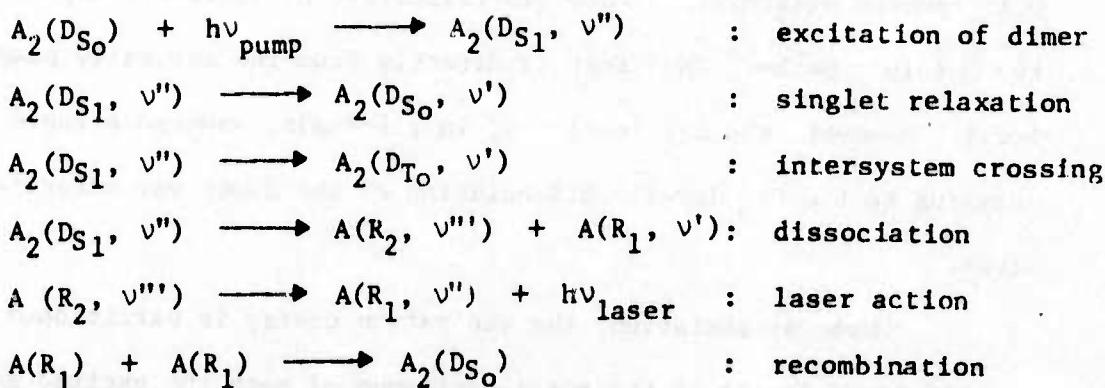
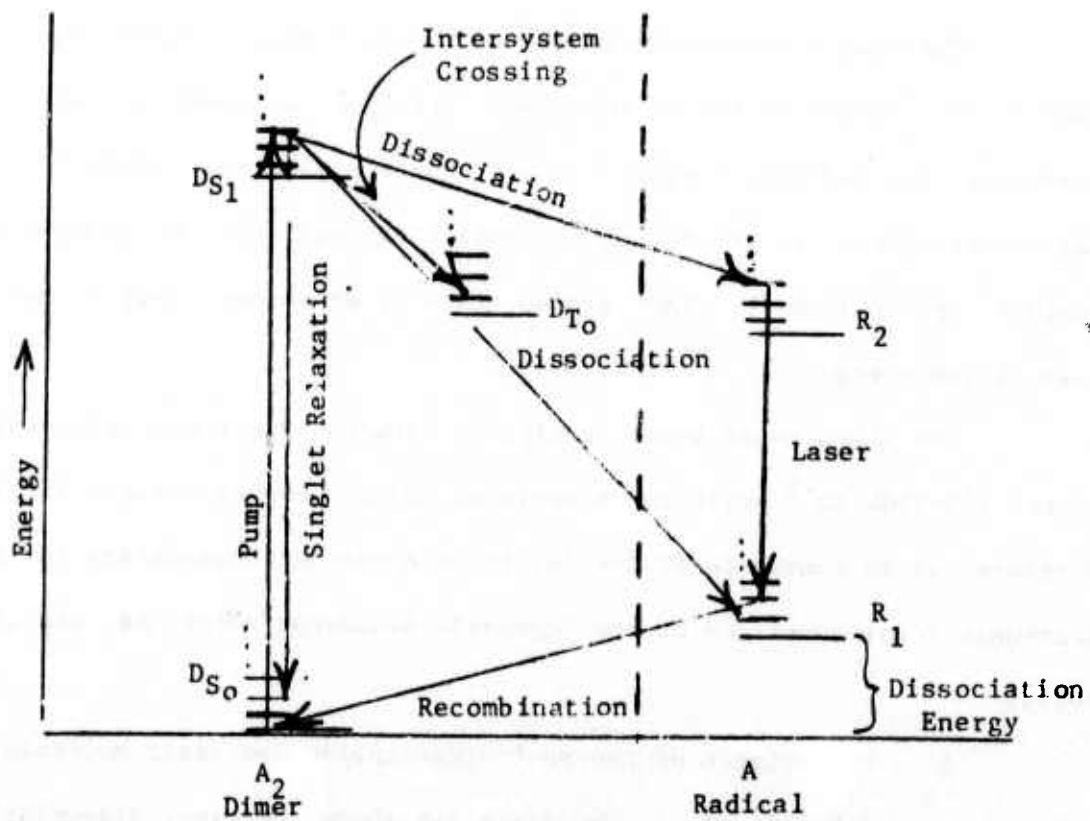


Figure 1. Photodissociation Dye Laser Molecule Structure and Kinetics

laser both the calculated and measured oscillator strengths for the first doublet-doublet electronic transition are always small. Thus, even though these transitions are allowed by selection rule considerations, they exhibit a partial "forbiddenness". Consequently, the radiative lifetime of the laser transitions can be expected to typically be a factor of a hundred times longer than in conventional dye lasers. This has been experimentally verified in some cases as will be discussed later. The longer lived upper laser level can permit a larger population density to be obtained and thereby allows the possibility of high energy output.

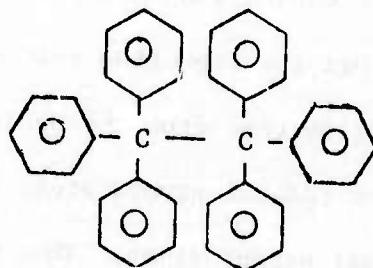
The ability of the photodissociation dye laser to operate on a cw basis requires, as usual, that the depletion rate of the lower laser level exceed the radiative transition rate from the upper to the lower laser level. The lower laser level is the radical ground state which is unstable to recombination back to the original parent dimer. Thus for a steady-state population inversion to be maintained, the radical recombination rate must be greater than the laser transition radiative rate.

III. PROPERTIES OF THE SELECTED PDL MOLECULES

A class of organic molecules known as the hexaarylethanes exhibit many of the prerequisites necessary for a PDL active media. At the start of the program five compounds from this class were selected and synthesized for further study. Details on the techniques used for synthesis of these molecules were given in the first semiannual report⁽¹⁾. What follows is an overview of the relevant properties of these materials known prior to our experimental effort.

A. Hexaphenylethane

The hexaphenylethane molecule can be represented schematically as:

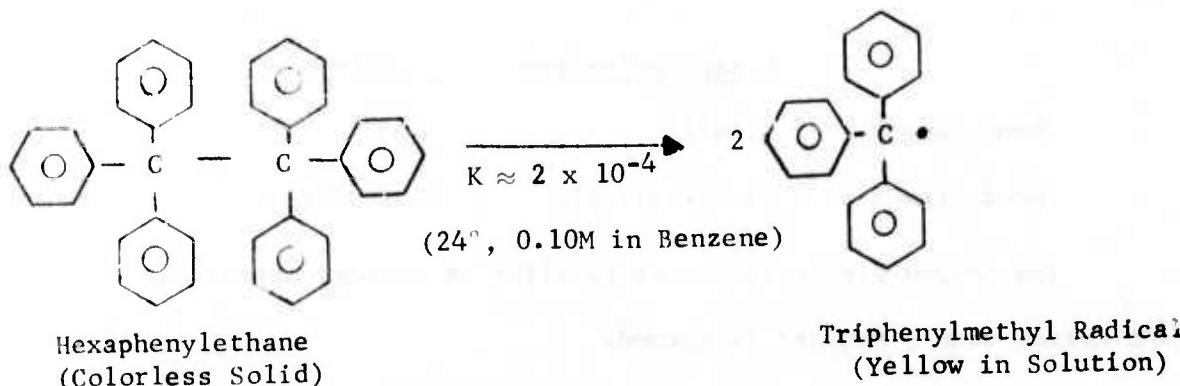


Although the accepted structure is actually non-planar, with a quinoid-type atomic arrangement, the above representation is adequate for the purposes of this discussion.

I. Chemical Properties

a. Dissociation Into Free Radicals

It has been clearly established for some time that hexaphenylethane thermally dissociates in non-reactive solvents to produce the intensely colored triphenylmethyl radical⁽²⁾:



The existence of the radical has been proven by a multiplicity of analytical techniques. For example, cryoscopic molecular weight determinations of such compounds in solution have shown that the apparent molecular weights were well below that of the dimer. In addition, spectrophotometric measurements have established that solutions of the dimer do not obey Beer's law; the intensity of absorption increases with dilution as would be predicted for the dissociation of a colorless compound into a colored radical. Finally, absolute methods of radical detection - magnetic susceptibility and electron spin resonance spectroscopy - have shown beyond doubt the thermal dissociation of hexaphenylethane into ground state triphenylmethyl radicals.

Two factors determine the position of the hexaphenylethane-triphenylmethyl equilibrium: (a) Steric effects and (b) Radical stability.

(a) Steric Effects - This factor favors the formation of radicals in two ways. First, there is a relief, upon dissociation, of the steric interactions in the ethane. In essence, the central carbon-carbon bond in the hexaphenylethane is weakened by the steric repulsion of the aromatic rings produced by interactions between the ortho-substituents. The bond weakening can be experimentally verified by comparison of the bond-length and strength of the central carbon-carbon bond in hexaphenylethane and the nonsterically-hindered ethane:

	<u>Hexaphenylethane</u>	<u>Ethane</u>
Bond Length	1.58 \AA	1.54 \AA
Bond Strength	11.5 kcal/mole	85 kcal/mole

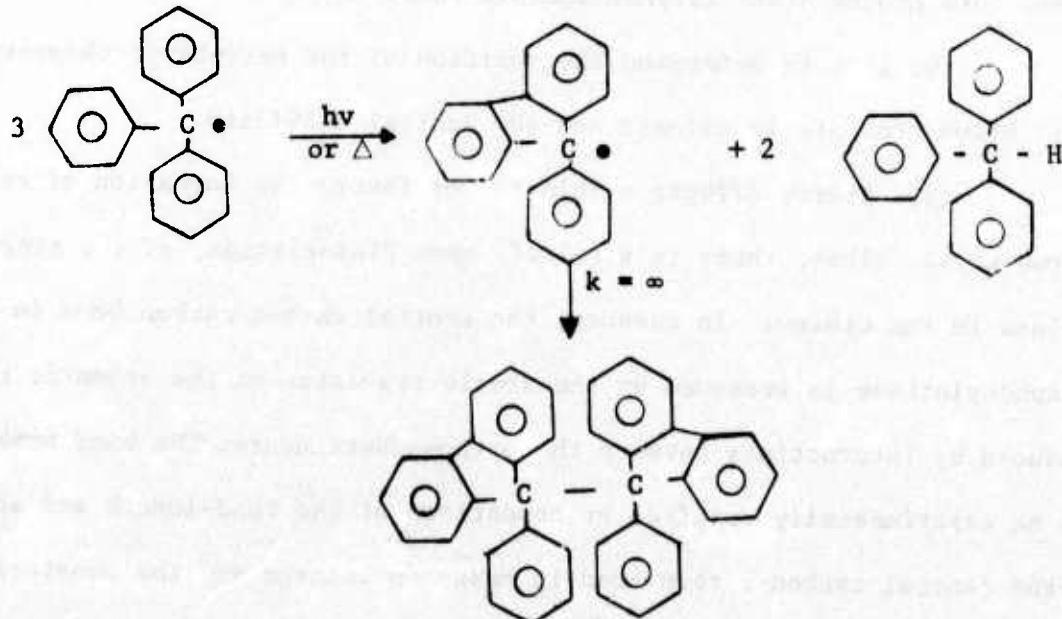
The second steric effect is typified by a steric hindrance to recombination once a radical is formed.

(b) Radical Stability - The stability of the triphenylmethyl radical is provided by a resonance stabilization effect resulting from the delocalization of the free electron throughout the three aromatic rings of the structure.

b. Deleterious Reactions

(1) Disproportionation

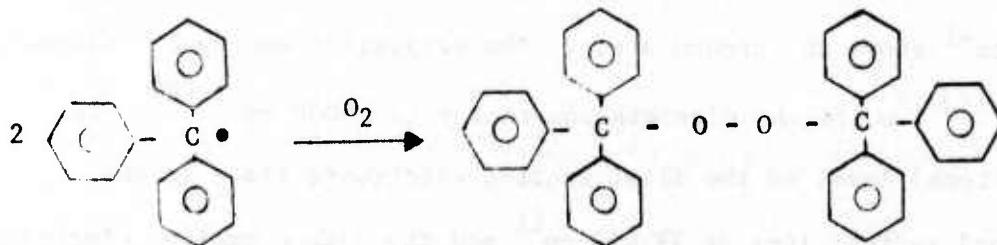
A number of chemical properties act to complicate the use of hexaphenylethane as a PDL active media candidate. These properties arise from the reactivity of the produced radicals. The first of these is their propensity towards disproportionation. This transformation is promoted by heat or light and is illustrated below:



In essence, two molecules of the radical become reduced at the expense of a third radical which is oxidized. For the triphenylmethyl radical, the products are triphenylmethane and the dehydro-dimer of 9-phenylfluorene. Measurements of the effect of this photochemical or thermal degradation on the use of hexaphenylethane as a laser media were presented in the second semiannual report⁽³⁾.

(2) Addition Reactions

The second deleterious reaction path which occurs when radicals are produced is the addition reaction. This involves the rapid absorption of atmospheric oxygen to form colorless triphenylmethyl peroxides:



As the radicals react, more dissociation must occur in order to maintain the dimer-radical equilibrium constant. In this way, a continuous depletion of both the radical and dimer concentration occurs until all the hexaphenylethane in solution has reacted to form the peroxide precipitate. As pointed out in the first semiannual report⁽¹⁾, careful preparation under vacuum conditions and subsequent storage and handling under a nitrogen atmosphere yield solutions that are quite stable with respect to such reactions. Spectrophotometric measurements of the radical concentration over a period of time in solutions we have prepared indicate a decrease of only several percent per week; and this decrease is probably due primarily to thermal disproportionation.

II. Spectroscopic Properties

The reported major bands in the electronic absorption spectra of hexaphenylethane and the triphenylmethyl radical are shown below along with the measured extinction coefficients⁽⁴⁾:

<u>Hexaphenylethane</u>	<u>Triphenylmethyl Radical</u>
$\lambda_{\max} = 3150 \text{ } \text{\AA}$ (using KBr pellet technique)	$\lambda_{\max} = 3450 \text{ } \text{\AA}$, $\epsilon = 11,000$
$\lambda_{\max} = 3130 \text{ } \text{\AA}$ (dissolved in cyclohexane)	$\lambda_{\max} = 5100 \text{ } \text{\AA}$, $\epsilon = 210$ (both in cyclohexane)

The major absorption bands can be associated with electronic transitions. The resulting dimer and radical energy level structure is shown in Figure 2. The first excited singlet level of the dimer, D_{S_1} , is $\sim 31,750 \text{ cm}^{-1}$ above the ground state. The activation energy for dissociation is $\sim 7000 \text{ cm}^{-1}$ ⁽⁵⁾ while the dissociation energy is $\sim 4000 \text{ cm}^{-1}$ ⁽⁶⁾. The ground vibrational level of the first excited electronic state in the triphenylmethyl radical lies at $19,410 \text{ cm}^{-1}$ and the second excited electronic level is at $\sim 29,000 \text{ cm}^{-1}$ above the ground state.

The mirror image symmetry of the absorption and fluorescence bands is illustrated in Figure 3. The spectra were originally reported by Lewis et al. (6) and were measured by suddenly cooling a solution of hexaphenylethane in EPA (5 parts ether, 5 parts isopentane, and 2 parts ethanol by volume) to liquid N₂ temperature (-190°C). It was reported that rapid cooling preserved the highly colored radicals in the clear EPA glass, and that under these conditions, there was no evidence of disproportionation. Unfortunately, no details regarding the measurement techniques used in taking the fluorescence data were presented--nor was the excitation source or wavelength described.

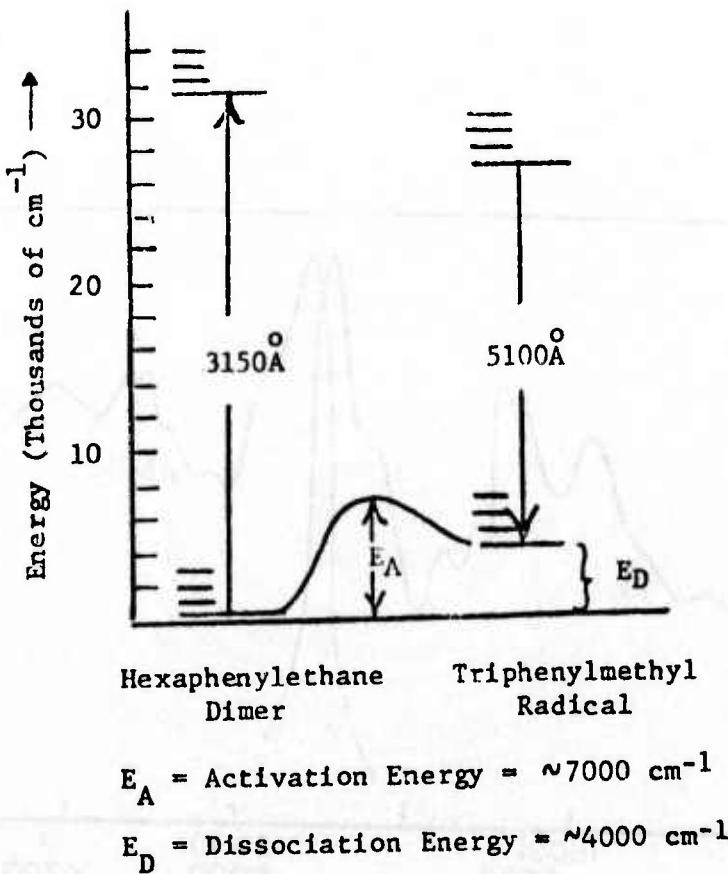


Figure 2. Energy Level Structure of the Hexaphenylethane-Triphenylmethyl System.

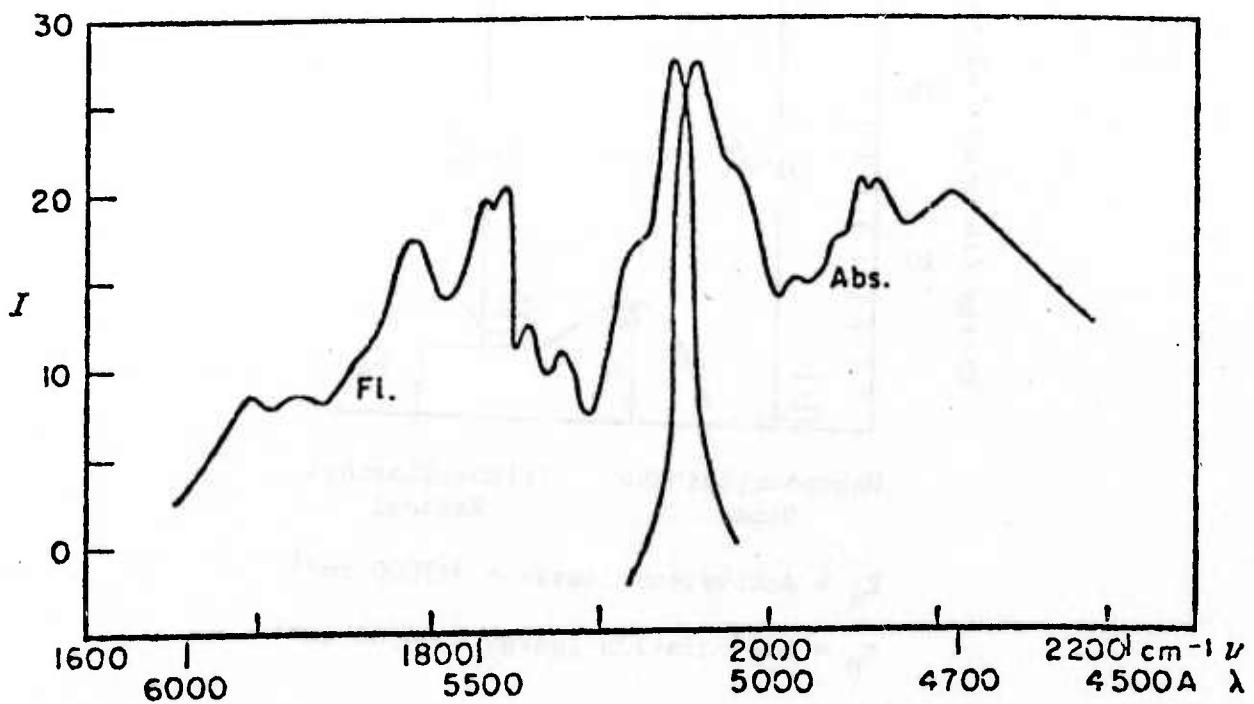


Figure 3. Mirror Symmetry of Absorption and Fluorescence Bands of the Triphenylmethyl Radical (in EPA mixed solvent at -190°C). Ref. (7).

More recently, Okamura et al. (7) performed time resolved fluorescence measurements on the triphenylmethyl and other methyl-substituted radicals which were trapped in rigid solvents at low temperature. The triphenylmethyl radical was prepared by the photolysis of triphenylmethane molecules at -190°C in a quartz cell using a low pressure mercury lamp. An N₂ laser emitting a 10 nsec, 40 kw peak power pulse at 3371 Å was used as the excitation source. The fluorescence decay consisted of a single exponential with the measured decay times being 280 nsec with ethyl alcohol as solvent, and 330 nsec using isopentane as the solvent. The very long fluorescence lifetimes were taken as evidence that the first doublet-doublet electronic transition in the radical has a forbidden character, although such transitions are allowed by the usual selection rule considerations. The possibility that the observed lifetimes were actually longer than the natural lifetimes because of complex formation of the excited state with the solvent, was ruled out by the fact that the difference of measured lifetimes in polar and nonpolar solvents was not appreciable.

B. Other Hexaarylethane Derivatives

The four other molecules that were synthesized have the advantage of being completely stable at room temperature with respect to dissociation into radicals. They all have strong absorption features in the UV. Their structures and UV absorption data are presented in the first semiannual report (1).

Three of the four molecules: sesquixanthydri1, pentaphenyl-ethane, and 1-p-biphenyl-1,1,2,2-tetraphenylethane are known to dissociate into colored radicals upon heating to ~100°C, indicating the weak bonding inherent in this group of molecules. Although no thermal or photochemical data with regard to radical production is available for 12-12' bifluoradenyl, its structure is sufficiently similar to hexaphenylethane to warrant its inclusion as a possible PDL material.

Unfortunately, solubility problems have precluded further study of sesquixanthydri1 as a potential PDL molecule. A spectroscopic study and evaluation of the three remaining molecules is presented in this report.

IV. EXPERIMENTAL EFFORT AND RESULTS

A. Hexaphenylethane

Aside from the synthesis of five potential PDL materials, the major part of the experimental effort reported in the previous semi-annual reports has been directed towards obtaining data that is relevant to assessing the possibility of laser action in the hexaphenylethane-triphenylmethyl radical system.

On the positive side, photodissociation of the hexaphenylethane dimer into excited state triphenylmethyl radicals has been demonstrated. Optical gains of $\sim .02 \text{ cm}^{-1}$ have been determined from absolute intensity measurements utilizing N_2 laser excitation (assuming the lower laser level to be unpopulated). Fluorescence lifetimes of the first excited triphenylmethyl radical level (the upper laser level) of $\sim 200 \text{ ns}$ have been measured at low temperature (-80°C).

On the negative side, the room temperature fluorescence lifetime is short ($\sim 15 \text{ nsec}$), the material must be handled in an oxygen-free environment because of the extreme reactivity of the thermally-generated radicals, and photochemical stability is poor. In addition, the effective quantum yield of fluorescence measured at the peak of the UV absorption band ($\sim 3350 \text{ \AA}$) is low. (These measurements were performed using an N_2 laser whose output (3371 \AA) essentially coincides with the peak of the absorption band.) For every 100 3371 \AA photons absorbed by the hexaphenylethane, only one photon comes out as triphenylmethyl radical fluorescence, giving an effective quantum yield of 1%. For further details on these measurements the reader is referred to the previous semiannual reports^(1,3).

The first topic that has been addressed during the present reporting period is that of the dependence of the hexaphenylethane fluorescence intensity on the excitation wavelength. This study was motivated by the fact that although the peak of the hexaphenylethane-triphenylmethyl UV absorption curve lies very close to the 3371 Å nitrogen laser wavelength, the cross section for photodissociation into excited state radicals may peak at a different wavelength, and as a result, larger fluorescence yields may be obtainable at other wavelengths even though the UV absorption is less. In addition, a knowledge of how the triphenylmethyl radical fluorescence intensity varies as a function of excitation wavelength is necessary in order to make an evaluation of different possible pumping mechanisms (e.g. laser vs flashlamp).

A frequency-doubled dye laser was used to provide a tunable UV source for these measurements. The peak of the fluorescent emission (5200 Å) from the hexaphenylethane solution was passed through a monochromator and detected by a 1P21 photomultiplier tube. The pulsed output was time-averaged with a PAR 160 boxcar integrator. A Molelectron J3-05 joulemeter was used to measure the incident laser intensity at each wavelength. Figure 4 shows the results of this series of measurements. The plotted ratio represents the hexaphenylethane fluorescence intensity normalized to the incident excitation intensity. If a comparison of this curve to the hexaphenylethane UV absorption curve (Figure 5) is made, one sees that they are quite similar in shape.

From the point of view of assessing an appropriate optical pump source for hexaphenylethane, these findings lead to some important conclusions. Optical pumping by a N₂ laser looks attractive for two reasons. First of all, the N₂ laser output of 3371 Å falls close to

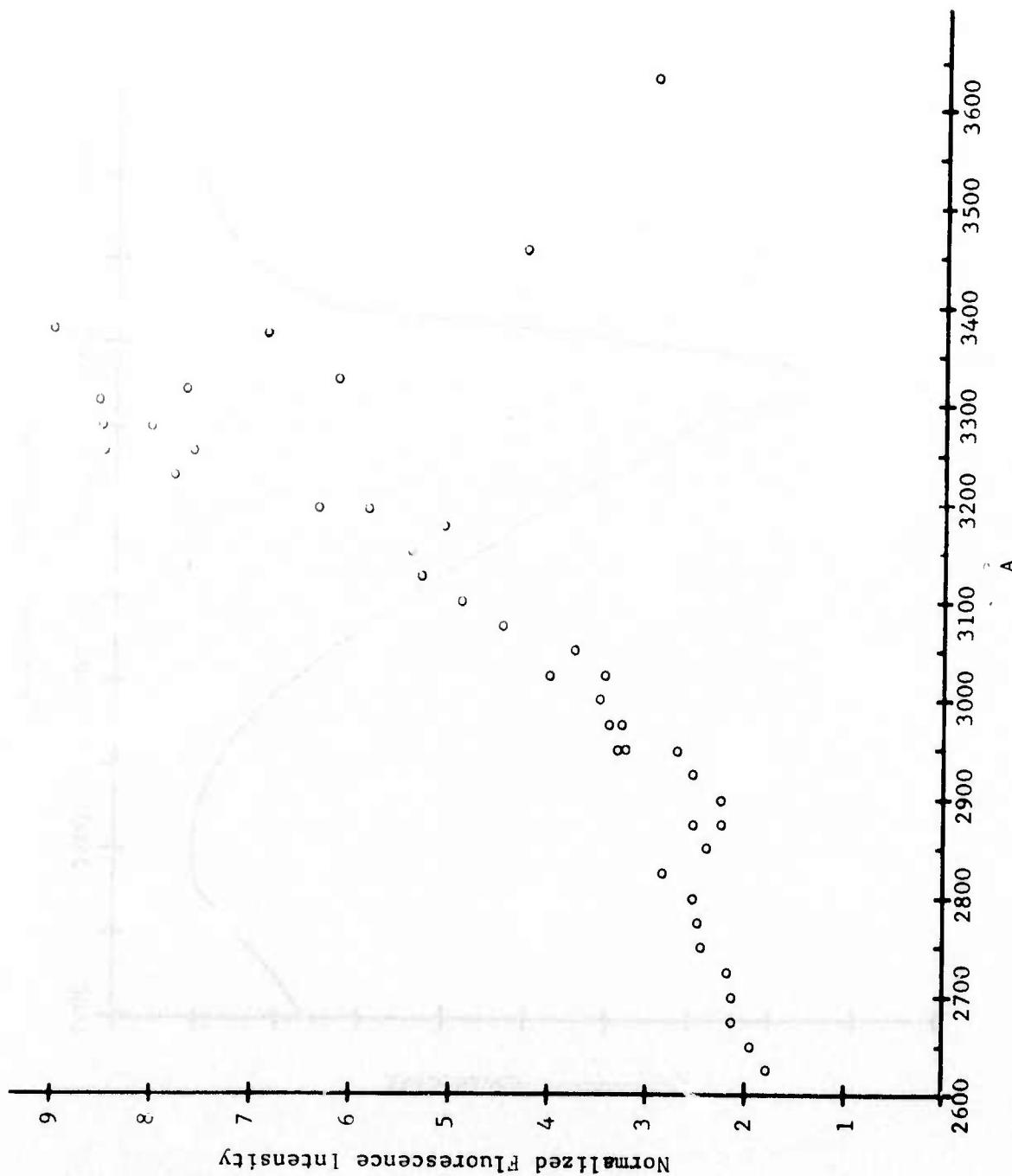


Figure 4. Hexaphenylethane fluorescence intensity plotted as a function of excitation wavelength. The fluorescence intensity shown is normalized to the incident intensity at each wavelength.

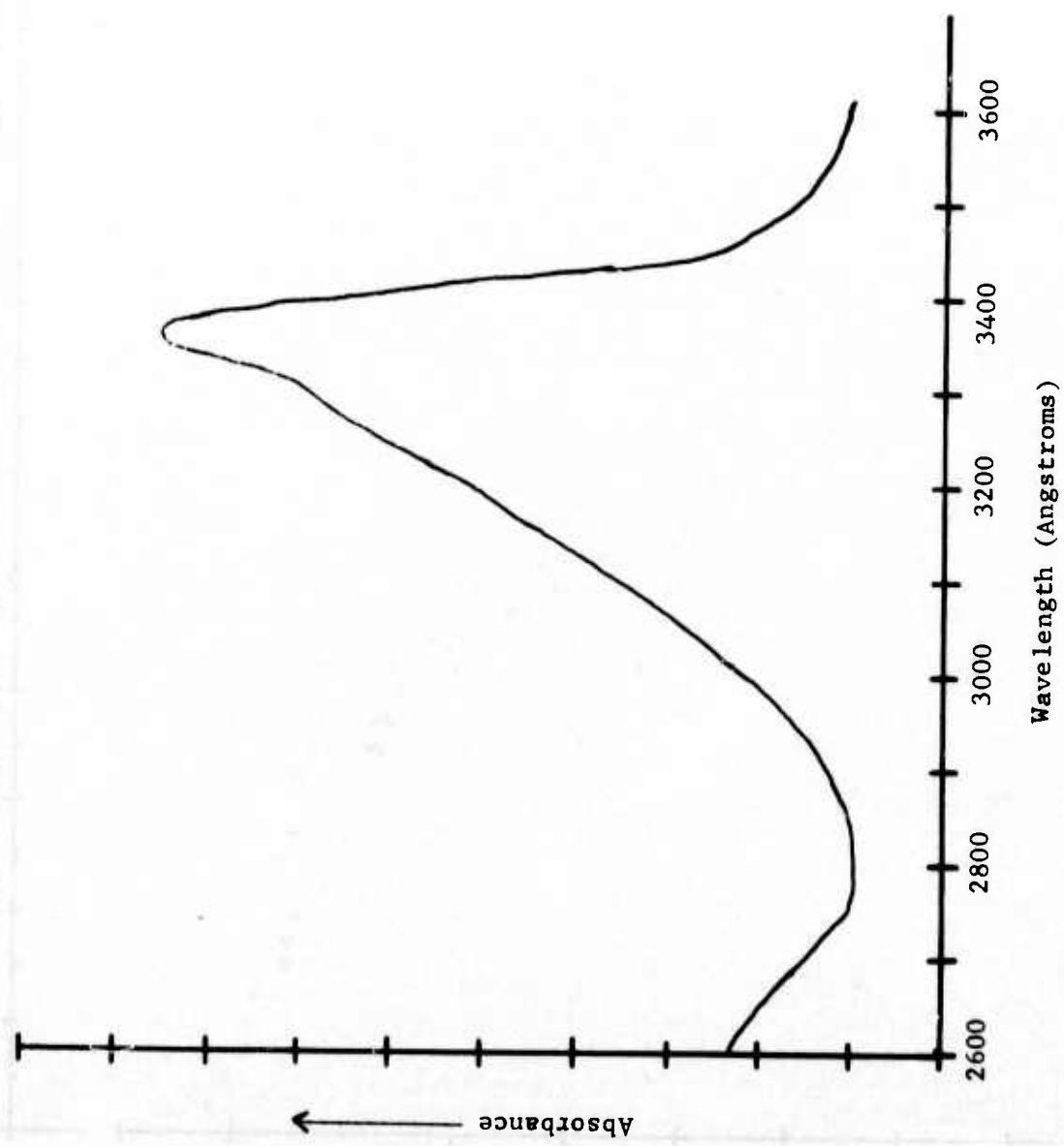


Figure 5. UV Absorption Spectrum of Hexaphenylmethane
(in iso-octane).

the peak of the UV absorption curve. Secondly, optical pumping at this wavelength not only results in the maximum absorption, but in the largest fluorescence quantum yield as well.

An attempt at achieving laser action in a solution of hexaphenylethane in isoctane has been made utilizing N₂ laser pumping. The 300 kw, 8 ns output of our N₂ laser was focused onto a quartz cell equipped with brewster angle windows. Two highly reflective dielectric coated mirrors served to form a resonant cavity. However, no laser action was attained from this configuration. Unfortunately, the excitation length one can achieve with the N₂ laser for a given power density is essentially limited by the beam geometry. In our case, using a cylindrical lens to form a line image, the effective excitation length is ~2.5 cm.

Taking our estimated value for the gain coefficient of .02 cm⁻¹, this means that the single pass gain through the hexaphenylethane solution is at most 5%, and this is not sufficient to overcome other cavity losses.

Xenon flashlamp pumping has been considered as a means of exciting a longer excitation length. In the N₂ laser pumping experiment, ~10 MW/cc are absorbed by the hexaphenylethane solution. In order to maintain this absorbed power density along a 15 cm length of active region would require a flashlamp output power equivalent to ~2 MW at 3371 Å. The fact that the flashlamp output is broadband and that both the hexaphenylethane absorption and triphenylmethyl radical fluorescence falls off rapidly as one moves further into the UV from 3371 Å means that the flashlamp output must be on the order of ~10 MW in the range 2800-3600 Å in order to be equivalent to the N₂ laser pump in exciting the hexaphenylethane solution. These large pumping requirements have led us to the conclusion that Xenon flashlamp pumping of hexaphenylethane would be highly impractical.

B. Other PDL Molecules

In addition to the work on hexaphenylethane, fluorescence spectra have been obtained during this reporting period for the other PDL molecules that were synthesized at the start of the program. The excitation source for all the spectra discussed below is a frequency doubled dye laser tuned to 2600 Å. All the molecules described below are strongly absorbing at this wavelength.

(a) Pentaphenylethane - Breaking of the central carbon-carbon bond results in the production of both triphenylmethyl and diphenylmethyl radicals. As mentioned previously thermal production of such radicals has been noted historically as color changes in heated solutions of pentaphenylethane. The fluorescence spectrum shown in Figure 6 does not show any features in the visible that can be associated with production of these radicals in an excited electronic state. Rather, a broad feature in the UV dominates the spectrum and is probably due to fluorescence of the pentaphenylethane dimer structure. We conclude that UV excitation of pentaphenylethane does not result in any significant photolytic production of electronically excited radicals.

(b) 1-p-biphenyl-1,1,2,2-tetraphenylethane - For this molecule as well, thermal dissociation into radicals has been observed by noting that clear solutions turn colored upon heating due to the visible absorption spectrum of the radicals. However, the fluorescence spectra we have taken (Figure 7) do not show any corresponding visible fluorescence that would be indicative of the formation of radicals in an electronically excited state. The weak fluorescence that is observed in the UV can be attributed to the dimer.

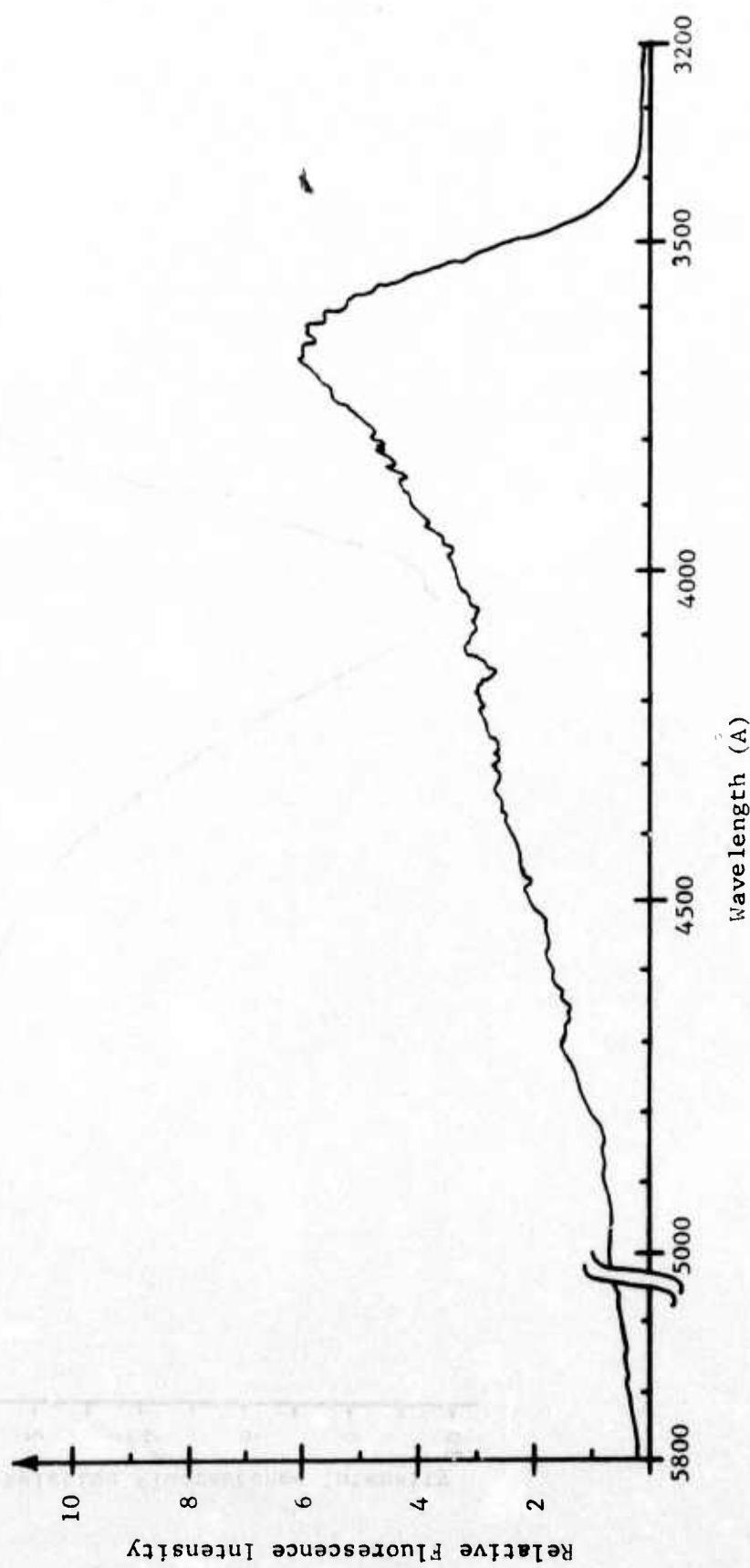


Figure 6. Fluorescence Spectrum of pentaphenylethane. The excitation source is a frequency doubled dye laser operating at 2600 Å.

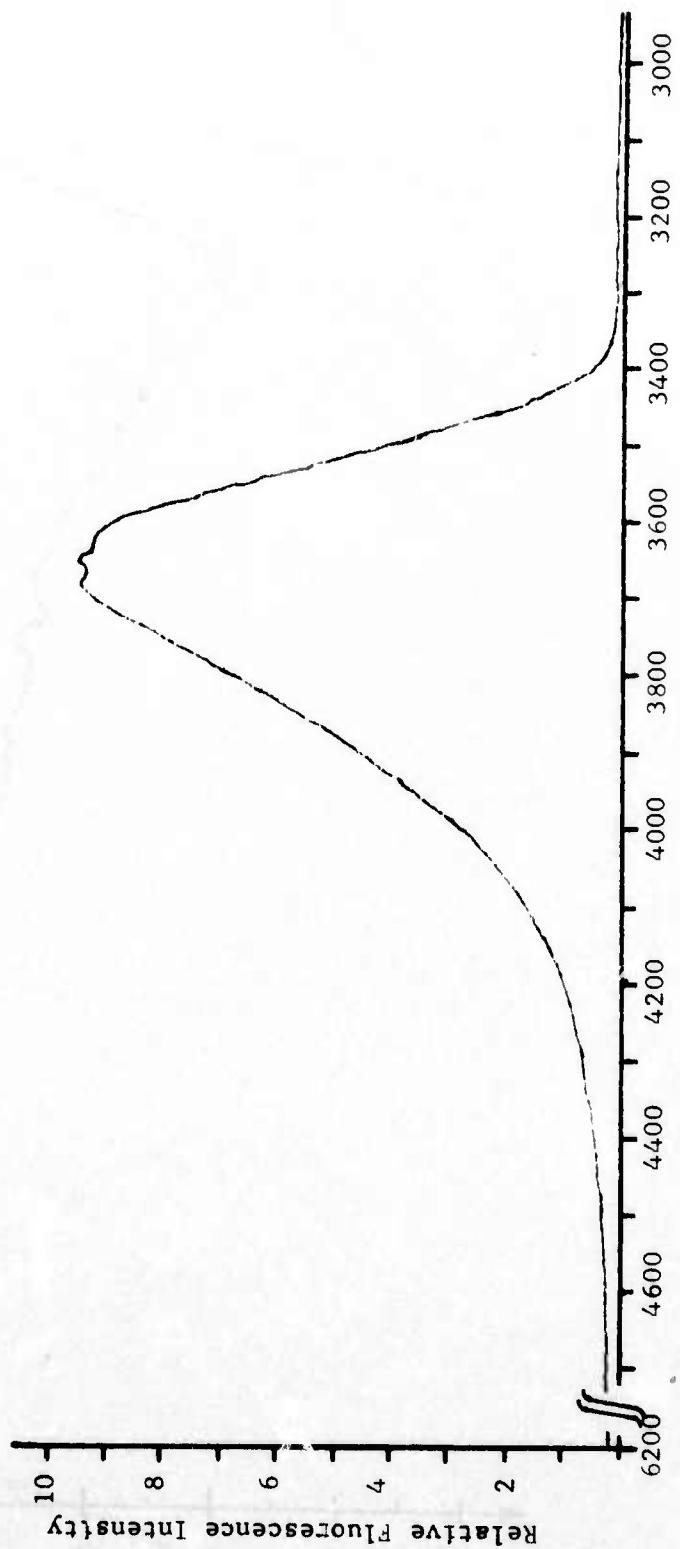
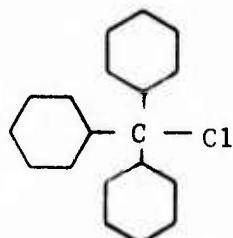


Figure 7. Fluorescence Spectrum of 1-p-biphenyl-1,1,2,2 tetraphenylethane excited by a frequency doubled dye laser operating at 2600 Å.

(c) 12-12' Bifluoradenyl - No evidence for thermal dissociation into radicals has been reported in the literature for this structure. The fluorescence spectra we have observed (Figure 8) indicate several peaks in the blue and UV. However, the fluorescence intensity is extremely weak.

The fluorescence lifetime for all these structures has been measured. The room temperature lifetimes are all ~ 10 ns with no observable change as the temperature of the medium is lowered to $\sim -100^{\circ}\text{C}$.

(d) We have investigated one other molecule that was not one of the original PDL molecules synthesized at the start of the program. This molecule is triphenylmethylchloride:



Irradiation of a solution containing this molecule with 2600°A light results in triphenylmethyl radical fluorescence. Photodissociation resulting in excited radical states is clearly seen to occur in this material. However, the fluorescence quantum yield is less than 1%, and therefore this molecule is not suitable as a PDL active media.

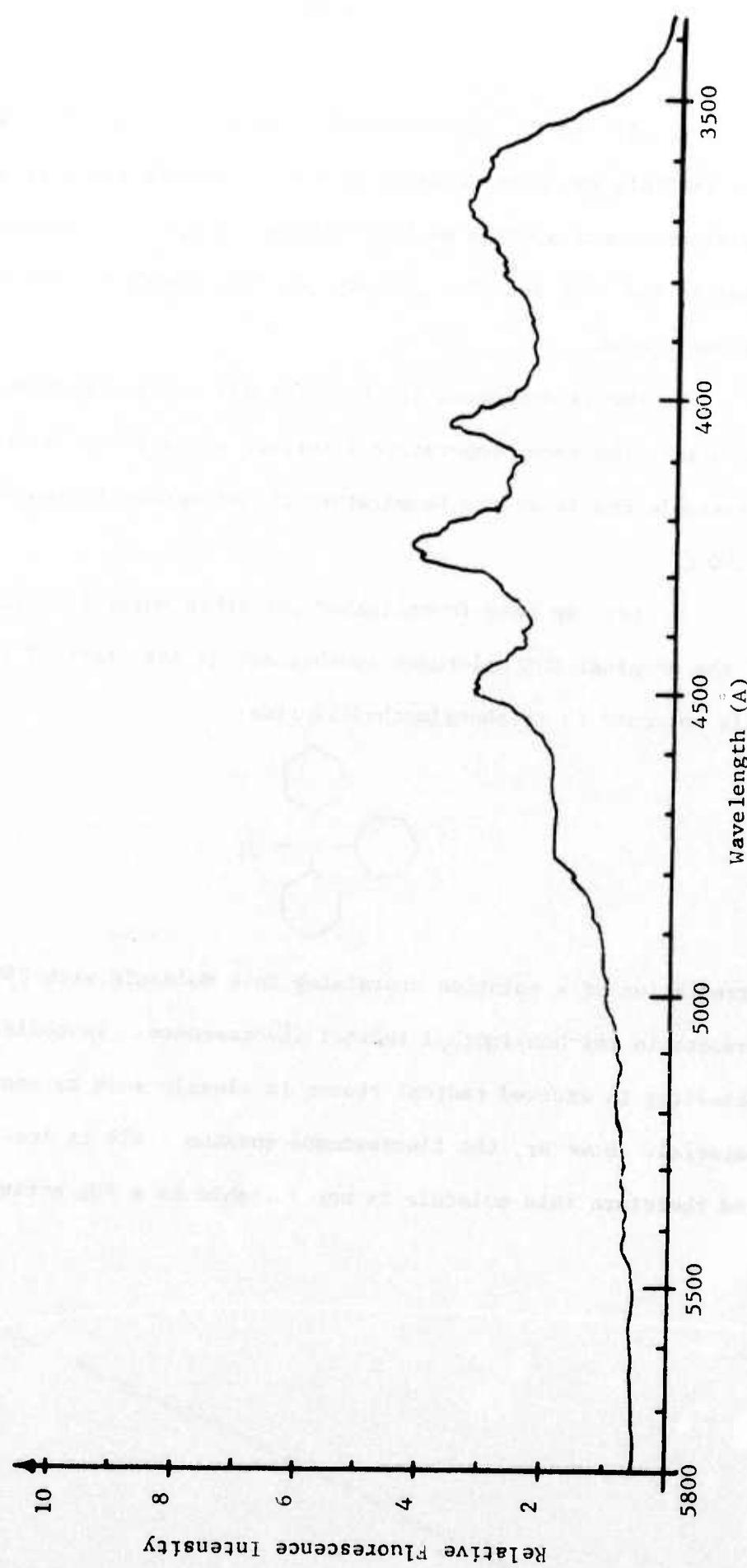


Figure 8. Fluorescence Spectrum of 12-12'bi fluoroadenyl excited by a frequency doubled dye laser operating at 2600 Å.

V. CONCLUSIONS

During this reporting period we have completed our measurements on the potential PDL molecules that were selected from the hexaarylethane group, and have evaluated their use as active media for the PDL scheme.

Fluorescence intensity measurements as a function of excitation wavelength have been made on the hexaphenylethane-triphenylmethyl radical system. These measurements indicate that the optimum optical pump source for the system is the N₂ laser. However, because the maximum gain for the system is low ($\sim .02 \text{ cm}^{-1}$), the length of the active media that the N₂ laser can excite is too short to overcome the single pass cavity losses.

The remaining hexaarylethane molecules synthesized at the start of the program have been studied as well. Their measured fluorescence lifetimes are ~ 10 ns in all cases. Their fluorescence spectra indicate that these molecules do not undergo appreciable photodissociation upon UV excitation (2600 Å) into excited electronically radicals. They are, therefore, not suitable as PDL active media.

Further progress in this program will involve synthesis of new candidates to fulfill the requirements of the PDL scheme. Possible choices of new groups of organic molecules to consider are the dilactones, alkoxytetraarylethanes, and tetraphenylallyl molecules. All these groups have been reported to reversibly dissociate into radicals as a function of temperature.

VI. REFERENCES

1. A. Kasdan, "Photodissociation Dye Laser," Semiannual Technical Report, Contract No. N00014-73-C0048, April, 1975.
2. A summary of the background information, relevant literature, and pertinent lead references for hexaphenylethane are included in the following sources.
 - a. A. R. Forrester, J. M. Hay and R. H. Thompson, "Organic Chemistry of Stable Free Radicals," Academic Press, Inc., New York (1968).
 - b. C. J. M. Stirling, "Radicals in Organic Chemistry," Oldbourne Press, London (1965).
 - c. Glenn H. Brown, Ed., "Photochromism," Techniques of Chemistry, Vol. III, Wiley-Interscience, New York (1971).
 - d. Henry Gilman, Ed., "Organic Chemistry--An Advanced Treatise," Volume 1, 2nd Ed., John Wiley and Sons, Inc., New York, (1963), pp. 581-630.
3. A. Kasdan, "Photodissociation Dye Laser," Semiannual Technical Report, Contract No. N00014-73-C0048, October, 1975.
4. Lankamp, Nauta, and MacLean, Tetra. Letts. 2, 249 (1968).
5. Ziegler, Orth, and Weber, Ann. 504, 131 (1933).
6. Ziegler and Ewald, Ann. 473, 169 (1929).
7. G. N. Lewis, D. Lipkin, and T. T. Magel, T. Am. Chem. Soc. 66, 1579 (1944).
8. T. Okamura, K. Obi, and I. Tanaka, Chem. Phys. Letts. 20, 90 (1973).

July 1975

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Director 2 copies

Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22209
ATTENTION: Program Management
DODAAC Code HX 1241

1 copy

Administrative Contracting Officer
Commander, Defense Contract Administration
Services District, Springfield
240 Route 22
Springfield, New Jersey 07081
DODAAC Code S3101A

2 copies

Director, Physics Program
Physical Sciences Division
Office of Naval Research
800 N. Quincy Street
Arlington, Virginia 22217
Ref. Contract #: N00014-75-C-0048
ATTENTION: M. B. White, Code 421

1 copy

University of Texas at Dallas
P.O. Box 30365
Dallas, TX 75230
ATTENTION: Professor Carl B. Collins

1 copy

ILC Laboratories, INC
ATTENTION: L. Noble
164 Commercial Street
Sunnyvale, CA 94086

1 copy

Lockheed Missile & Space Co.
ATTENTION Dr. R. C. Ohlman
Palo Alto Research Laboratories
Palo Alto, CA 94304

July 1975

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Office of Naval Research Department of the Navy Attn: Physics Program Arlington, Virginia 22217	3 copies
Naval Research Laboratory Department of the Navy Attn: Technical Library Washington, D. C. 20375	1 copy
Office of the Director of Defense Research and Engineering Information Office Library Branch The Pentagon Washington, D. C. 20301	1 copy
U. S. Army Research Office Box CM Duke Station Durham, NC 27706	1 copy
Defense Documentation Center Cameron Station Alexandria, VA 22314	12 copies
Defender Information Analysis Center Battelle Memorial Institute 501 King Avenue Columbus, OH 43201	1 copy
Director Office of Naval Research Branch Office 536 South Clark Street Chicago, IL 60615	1 copy
San Francisco Area Office Office of Naval Research 760 Market Street, Room 447 San Francisco, CA 94102	1 copy
Air Force Office of Scientific Research Department of the Air Force Washington, DC 22209	1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Office of Naval Research Branch Office
Attn: Dr. Robert Behringer
1030 East Green Street
Pasadena, CA 91106

1 copy

Code 102 1P(ONRL)
Office of Naval Research
700 N. Quincy Street
Arlington, VA 22217

6 copies

Defense Advanced Research Projects Agency
1400 Wilson Blvd.
Arlington, VA 22209
Attn: Director, Laser Division

1 copy

ODDR&E
Pentagon
Washington, DC 20301
Attn: Ass't Dir. (Space and Advanced Systems)

1 copy

Office of the Ass't Secretary of Defense
System Analysis (Strategic Programs)
Washington, DC 20301
Attn: Mr. Gerald R. McNichols

1 copy

U. S. Arms Control and Disarmament Agency
Dept. of State Bldg., RM 4931
Washington, DC 20451
Attn: Dr. Charles Henkin

1 copy

Energy Research Development Agency
Division of Military Applications
Washington, DC 20545

1 copy

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, OH 44135
Attn: Dr. John W. Dunning, Jr.
(Aerospace Res. Engineer)

1 copy

National Aeronautics & Space Administration
Code RR, FOB 10B
600 Independence Ave. SW
Washington, DC 20546

1 copy

National Aeronautics and Space Administration
Ames Research Center
Moffet Field, CA 94035
Attn: Mr. Robert L. McKenzie
Dr. Kenneth W. Billman

1 copy
1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Department of the Army
Office of the Chief of RD&A
Washington, DC 20310
Attn: DARD-DD
DAMA-WSM-T

1 copy
1 copy

Department of the Army
Office of the Deputy Chief of Staff
for Operations & Plans
Washington, DC 20310
ATTN: DAMO-RQD

2 copies

Ballistic Missile Defense Program Office (BMDPO)
The Commonwealth Bldg.
1300 Wilson Blvd.
Arlington, VA 22209
Attn: Mr. Albert J. Bast, Jr.

3 copies

U. S. Army Missile Command
Research and Development Division
Redstone Arsenal, ALA 35809
Attn: Army High Laser Energy Programs

2 copies

Commander
Rock Island Arsenal
Rock Island, IL 61201
Attn: SARRI-LR, Mr. J. W. McGarvey

1 copy

Commanding Officer
U. S. Army Mobility Equipment R&D Center
Ft. Belvoir, VA 22060
ATTN: SMFFB-MW

1 copy

Commander
U. S. Army Armament Command
Attn: AMSAR-RDT
Rock Island, IL 61201

1 copy

Director
Ballistic Missile Defense Advanced Technology Center
PO Box 1500
Huntsville, AL 35807
Attn: ATC-O
ACT-T

1 copy
1 copy

Commander
U. S. Army Material Command
Alexandria, VA 22304
Attn: Mr. Paul Chernoff (AMCRD-T)
Dr. B. Zarwyn (AMCRD-T)

1 copy
1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Commanding General
U. S. Army Munitions Command
Dover, NH 07801
Attn: Mr. Gilbert F. Chesnov (AMSMU-R) 1 copy

Director
U. S. Army Ballistic Res. Lab
Aberdeen Proving Ground, MD 21005
Attn: Dr. Robert Eichelberger 1 copy
Mr. Frank Allen 1 copy
Dr. E. C. Alcarez 1 copy

Commandant
U. S. Army
Air Defense School
Ft. Bliss, TX 79916 1 copy
Attn: Air Defense Agency
ATSA-CTD-MS 1 copy

Commanding General
U. S. Army Combat Dev. Command
Ft. Belvoir, VA 22060
Attn: Director of Material, Missile Div. 1 copy

Commander
U. S. Army Training & Doctrine Command
Attn" ATCD-CF
Ft. Monroe, VA 23651 1 copy

Commander
U. S. Army Frankford Arsenal
Philadelphia, PA 19137
Attn: Mr. M. Elnick SARFA-FCD
Bldg. 201-3 1 copy

Commander
U. S. Army Electronics Command
Ft. Monmouth, NJ 07703
Attn: AMSEL-CT-L, Dr. R. G. Buser 1 copy

Commander
U. S. Army Combined Arms Combat Developments Activity
Ft. Leavenworth, KS 66027 1 copy

National Security Agency
Ft. Geo. g. Meade, MD 20755
Attn: R. C. Foss A763 1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Deputy Commandant for Combat & Training Developments
U. S. Army Ordnance Center and School
Attn: ATSL-CTD-MS-R
Aberdeen Proving Ground, MD 21005

1 copy

Commanding Officer
USACDC CBR Agency
Ft. McClellan, AL 36201
Attn: CDCCBR-MR (Mr F. D. Poer)

1 copy

Department of the Navy
Office of the Chief of Naval Operations
Pentagon 5C739
Washington, DC 20350
Attn: (OP 982F3)

1 copy

Office of Naval Research
Attn: Dr. Fred Quelle
495 Summer Street
Boston, MA 02210

1 copy

Department of the Navy
Deputy Chief of Naval Material (Dev.)
Washington, DC 20360
Attn: Mr. R. Gaylord (MAT 032B)

1 copy

Naval Missile Center
Point Mugu, CA 93042
Attn: Gary Gibbs (Code 5352)

1 copy

Naval Research Lab
Washington, DC 20375
Attn: (Code 5503-LTPO)
Dr. P. Livingston (Code 55060) 1 copy
Dr. A. I. Schindler (Code 6330) 1 copy
Dr. H. Shenker (Code 6530) 1 copy
Mr. D. J. McLaughlin (Code 5560) 1 copy
Dr. John L. Walsh (Code 5503) 1 copy

High Energy Laser Project Office
Department of the Navy
Naval Sea Systems Command
Washington, DC 20360
Attn: Capt. J. G. Wilson, USN (PMS-405)

1 copy

Superintendent
Naval Postgraduate School
Monterey, CA 93940
Attn: Library (Code 2124)

1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Cont. acts

Navy Radiation Technology Liaison Office
Air Force Weapons Lab. (NLO)
Kirtland AFB, NM 87117

1 copy

Naval Surface Weapons Center
White Oak

Silver Spring, MD 20910

Attn: Dr. Leon H. Schindel (Code 310)
Dr. E. Leroy Harris (Code 313)
Mr. K. Enkenhus (Code 034)
Mr. J. Wise (Code 047)
Technical Library

1 copy
1 copy
1 copy
1 copy
1 copy

U. S. Naval Weapons Center
China Lake, CA 93555

Attn: (Code 5114)
Technical Library

1 copy
1 copy

HQ USAF (AF/RDPS

Pentagon

Washington, DC 20330

Attn: Lt. Col A. J. Chiota

1 copy

HQ AFSC/XRLW

Andrews AFB

Washington, DC 20331

Attn: Maj. J. M. Walton

1 copy

HQ AFSC (DLCAW)

Andrews AFB

Washington, DC 20331

Attn: Maj. H. Axelrod

1 copy

Air Force Weapons Lab

Kirtland AFB, NM 87117

Attn: LR

AL

4 copies
2 copies

HQ SAMSO (XRTD)

PO Box 92960, Worldway Postal Center

Los Angeles, CA 90009

Attn: Lt. Dorian DeMaio (XRTD)

1 copy

AF Avionics Lab (TSD)

Wright Patterson AFB, OH 45433

Attn: Mr. K. Hutchinson

1 copy

Dept. of the Air Force

Air Force Materials Lab. (AFSC)

Wright Patterson AFB, OH 45433

Attn: Maj. Paul Elder (LPS)

Laser Window Group

1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

HQ Aeronautical Systems Div.
Wright Patterson AFB, OH 45433
Attn: XRF - Mr. Clifford Fawcett 1 copy

Rome Air Development Command
Griffiss AFB
Rome, NY 13440
Attn: Mr. R. Urtz (OCSE) 1 copy

HQ Electronics Systems Div. (ESL)
L. G. Hanscom Field
Bedford, MA 01730
Attn: Mr. Alfred E. Anderson (XRT)
Capt. James C. Jalbert (XRJ)
Technical Library 1 copy
1 copy
1 copy

Air Force Rocket Propulsion Lab.
Edwards AFB, CA 93523
Attn: B. R. Bornhorst, (LKCG) 1 copy

Air Force Aero Propulsion Lab.
Wright Patterson AFB, OH 45433
Attn: Col. Walter Moe (CC) 1 copy

Dept. of the Air Force
Foreign Technology Division
Wright Patterson AFB, OH 45433
Attn: PDTN 1 copy

CINCSAC/INEP
Offutt AFB, NE 68113 1 copy

Commandant of the Marine Corps
Scientific Advisor (Code RD-1)
Washington, D. C. 20380 1 copy

USAF/INA
Washington, DC 20330
Attn: Lt. Col. W. M. Truesdell 1 copy

Aerospace Research Labs., (AP)
Wright Patterson AFB, OH 45433
Attn: Lt. Col. Max Duggins 1 copy

Defense Intelligence Agency
Washington, DC 20301
Attn: Mr. Seymour Berler (DTIB) 1 copy

Central Intelligence Agency
Washington, DC 20505
Attn: Mr. Julian C. Nall 1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Analytic Services, Inc.
5613 Leesburg Pike
Falls Church, VA 22041
Attn: Dr. John Davis 1 copy

Aerospace Corp.
PB Box 92957
Los Angeles, CA 90009
Attn: Dr. G. P. Millburn 1 copy

Airesearch Manuf. Co.
9851 - 9951 Sepulveda Blvd.
Los Angeles, CA 90009
Attn: Mr. A. Colin Stancliffe 1 copy

Atlantic Res. Corp.
Shirley Highway at Edsall Rd.
Alexandria, VA 22314
Attn: Mr. Robert Naismith 1 copy

AVCO Everett Res. Lab.
2385 Revere Beach Parkway
Everett, MA 02149
Attn: Dr. George Sutton
Dr. Jack Daugherty 1 copy
1 copy

Battelle Columbus Laboratories
505 King Avenue
Columbus, OH 43260
Attn: Mr. Fred Tietzel (STOIAC) 1 copy

Bell Aerospace Co.
Buffalo, NY 14240
Attn: Dr. Wayne C. Solomon 1 copy

Boeing Co.
PO Box 3999
Seattle, WA 98124
Attn: Mr. M. I. Gamble (2-1460, MS 8C-88) 2 copies

Electro-Optical Systems
300 N. Halstead
Pasadena, CA 91107
Attn: Dr. Andrew Jensen 1 copy

FSL Inc.
495 Java Drive
Sunnyvale, CA 94086
Attn: Arthur Einhorn 1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

General Electric Co.
Space Division
PO Box 8555
Philadelphia, PA 19101
Attn: Dr. R. R. Sigismonti
Dr. C. E. Anderson

1 copy
1 copy

General Electric Co.
100 Plastics Avenue
Pittsfield, MA 01201
Attn: Mr. D. G. Harrington
(Room 1044)

1 copy

General Research Corp.
PO Box 3587
Santa Barbara, CA 93105
Attn: Dr. R. Holbrook

1 copy

General Research Corp.
1501 Wilson Blvd., Suite 700
Arlington, VA 22209
Attn: Dr. Giles F. Crimi

1 copy

Hercules, Inc.
Industrial System Dept.
Wilmington, DE 19899
Attn: Dr. R. S. Voris

1 copy

Hercules, Inc.
PO Box 210
Cumberland, MD 21502
Attn: Dr. Ralph R. Preckel

1 copy

Hughes Research Labs.
3011 Malibu Canyon Road
Malibu, CA 90265
Attn: Dr. D. Forster
Dr. A. N. Chester
Dr. Viktor Evtuhov

1 copy
1 copy
1 copy

Hughes Aircraft Co.
Aerospace Group - Systems Division
Canoga Park, CA 91304
Attn: Dr. Jack A. Alcalay

1 copy

Hughes Aircraft Co.
Centinela and Teale Streets
Bldg. 6, MS E-125
Culver City, CA 90230
Attn: Dr. William Yates

1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Institute for Defense Analysis
400 Army Navy Dr.
Arlington, VA 22202
Attn: Dr. Alvin Schnitzler

1 copy

John Hopkins University
Applied Physics Lab.
8621 Ga. Ave.
Silver Spring, MD 20910
Attn: Dr. Albert M. Stone
Dr. R. E. Gorozdos

1 copy
1 copy

Lawrence Livermore Lab.
PO Box 808
Livermore, CA 94550
Attn: Dr. R. E. Kidder
Dr. E. Teller
Dr. Joe Fleck

1 copy
1 copy
1 copy

Los Alamos Scientific Lab.
PO Box 1663
Los Alamos, NM 87544
Attn: Dr. Keith Boyer

1 copy

Hulejian and Associates, Inc.
Del Amo Financial Center
Suite 500
21515 Hawthorne Blvd
Torrance, CA 90503

1 copy

Lockheed Palo Alto Res. Lab.
3251 Hanover St.
Palo Alto, CA 94303
Attn: L. R. Lunsford
Orgn. 52-24 Bldg. 201

1 copy

Mathematical Sciences Northwest, Inc.
PO Box 1887
Bellevue, WN 98009
Attn: Mr. Peter H. Rose
Dr. Abraham Hertzberg

1 copy
1 copy

Martin Marietta Corp.
PO Box 179
Mail Station 0471
Denver, CO 80201
Attn: Mr. Stewart Chapin
Mr. Scott Giles

1 copy
1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Massachusetts Institute of Technology
LINCOLN LAB
PO Box 73
Lexington, MA 02173
Attn: Dr. S. Edelberg 1 copy
Dr. L. C. Marquet 1 copy
Dr. J. Freedman 1 copy
Dr. G. P. Dinneen 1 copy
Dr. R. H. Rediker 1 copy

Mc Donnell Douglas Astronautics Co.
5301 Bolsa Ave.
Huntington Beach, CA 92647
Attn: Mr. P. L. Klevatt
Dept. A3-830-BBFO, M/S 9 1 copy

Mc Donnell Douglas Res. Labs.
Dept. 220, Box 516
St. Louis, MO 63166
Attn: Dr. D. P. Ames 1 copy

MITRE Corp.
PO Box 208
Bedford, MA 01730
Attn: Mr. A. C. Cron 1 copy

North American Rockwell Corp.
Autonetics Div.
3370 Miraloma Ave.
Anaheim, CA 92803
Attn: Mr. T. T. Kumagi
C/476 Mail Code HAL8 1 copy

Northrop Corp.
3401 West Broadway
Hawthorne, CA 90250
Attn: Dr. Gerard Hasserjian
Laser Systems Dept. 1 copy

Dr. Anthony N. Pirri
Physical Sciences Inc.
18 Lakeside Office Park
Wakefield, MA 01880 1 copy

RAND Corp
1700 Main Street
Santa Monica, CA 90406
Attn: Dr. Claude R. Culp/Mr. G. A. Carter 1 copy

Raytheon Co.
28 Seyon St.
Waltham, MA 02154
Attn: Dr. Frank A. Horrigan (Res. Div.) 1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Raytheon Co. (Equipment Division) Boston Post Road Sudbury, MA 01776 Attn: Dr. Charles Sonnenschien	1 copy
Raytheon Co. Bedford Labs Missile Systems Div. Bedford, MA 01730 Attn: Dr. H. A. Mehlhorn	1 copy
Riverside Research Institute 80 West End St. New York, NY 10023 Attn: Dr. L. H. O'Neill Dr. John Bose Miss Helen Cressman (HPEGL Library)	1 copy 1 copy 1 copy
R&D Associates, Inc. PO Box 3580 Santa Monica, CA 90431 Attn: Dr. R. E LeLevier Dr. R. Hundley	1 copy 1 copy
Rockwell International Corp. 3370 Miraloma Corp. Anaheim, CA 92803 Attn: R. E. Hovda (DB 29) Dr. J. Winocur (D/523, HAL4)	1 copy 1 copy
Rockwell International Corp Rocketdyne Div. Albuquerque Districe Office 3636 Menaul Blvd, NE, Suite 211 Albuquerque, NM 87110 Attn: C. K. Kraus, Mgr.	1 copy
SANDIA Corp. PO Box 5800 Albuquerque, NM 87115 Attn: Dr. Al Narath	1 copy
Stanford Research Institute Menlo Park, CA 94025 Attn: Dr. H. E. Lindberg Dr. J. E. Malick	1 copy 1 copy
Science Applications Inc. 1911 N. Ft. Meyer Drive Arlington, VA 22209 Attn: L. Peckham	1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

Science Applications Inc.
PO Box 328
Ann Arbor, MI 48103
Attn: R. E. Meredith

1 copy

Science Applications Inc.
6 Preston Court
Bedford, MA 01703
Attn: R. Greenberg

1 copy

Science Applications Inc.
PO Box 2351
La Jolla, CA 92037
Attn: Dr. John Asmus

1 copy

Systems, Science and Software
PO Box 1620
LaJolla, CA 92037
Attn: Alan F. Klein

1 copy

Systems Consultants, Inc.
1050 31st St. NW
Washington, DC 20007
Attn: Dr. R. B. Keller

1 copy

Thiokol Chemical Corp.
WASATCH Div.
PO Box 524
Brigham City, UT 84302
Attn: Mr. J. E. Hansen

1 copy

TRW Systems Group
One Space Park
Bldg. R-1 RM 1050
Redondo Beach, CA 90278
Attn: Mr. Norman Campbell

1 copy

United Aircraft Res. Labs
400 Main Street
East Hartford, CT 06108
Attn: Mr. G. H. McLafferty
Mr. Albert Angelbeck

3 copies
1 copy

United Aircraft Corp.
Pratt and Whitney Acft. Div.
Florida R&D Center
West Palm Beach, FL 33402
Attn: Dr. R. A. Schmidtke
Mr. Ed Pinsley

1 copy
2 copies

Distribution List for ARPA #Order 1806/1807 Unclassified Contracts

VARIAL Associates
EIMAC Div
301 Industrial Way
San Carlos, CA 94070
Attn: Mr. Jack Quinn

1 copy

Vought Systems Div.
LTV Aerospace Corp.
PO Box 5907
Dallas, TX 75222
Attn: Mr. F. G. Simpson
Mail Station 254142

1 copy

Westinghouse Electric Corp
Defense and Space Center
Friendship International Airport - Box 746
Baltimore, MD 21203
Attn: Mr. W. F. List

3 copies

Westinghouse Res. Labs
Beulah Road, Churchill Boro
Pittsburgh, PA 15235
Attn: Dr. E. P. Riedel
Mr. R. L. Hundstad

1 copy
1 copy

United Aircraft Company Research Laboratories
Attn: A. J. DeMaria
East Hartford, CT 06108

1 copy

Airborne Instruments Laboratory
Attn: F. Pace
Walt Whitman Road
Melville, NY 11746

1 copy

Stanford Research Institute
Menlo Park, CA 94025
Attn: Dr. F. T. Smith

1 copy

General Electric R&D Center
Schenectady, NY 12305
Attn: Dr. Donald White

1 copy

Cleveland State University
Cleveland, OH 44115
Attn: Dean Jack Soules

1 copy

Esso Research and Engineering Co.
Attn: D. Grafstein
PO Box 8
Linden, NJ 07036

1 copy

Distribution List for ARPA Order #1806/1807 Unclassified Contracts

University of Maryland
Department of Physics and Astronomy
Attn: D. Curry
College Park, MD 20742

1 copy

Sylvania Electric Products, Inc.
Attn: L. M. Osterink
100 Fergeson Drive
Mountain View, CA 94040

1 copy

North American Rockwell Corp.
Autonetics Division
Attn: R. Gudmundsen
3370 Miraloma Avenue
Anaheim, CA 92803

1 copy

Massachusetts Institute of Technology
Attn: Prof. A. Javan
77 Massachusetts Avenue
Cambridge, MA 02138

1 copy